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By M. Kramer

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SUMMARY

The large wind tunnel of the DVL which has been in operation since the end of 1934, is now past the experimental stage. According to the cones fixed, an elliptical stream with axes 5 by 7 meters (16.4 by 23 feet) and length 9 meters (29.53 feet), or a stream 6 by 8 meters (19.7 by 26.25 feet) in cross section and 11 meters (36.08 feet) in length, is available. The top speed with the smaller cone is 65 meters per second (213 feet per second). The accuracy of the flow as regards direction and speed corresponds to the value for good tunnels. As regards freedom from turbulence, the tunnel yields the best values hitherto obtained and is very near the value in free flight. The original occasionally occurring longitudinal oscillations of the air column are now eliminated.

The testing equipment consists of an automatic six-component balance and a test rig for propellers and engines up to 650 horsepower. A three-component balance for measurements on full-scale airplanes, including running power plant, is in course of development.

The tunnel was built under the direction of M. Schilhansl, Dr. Eng. (propellers, speed regulation, aerodynamic points); M. Kramer, Dr. Eng. (measuring apparatus, aerodynamic points, operation); and Engineer H. Brenner (constructional lay-out, building direction).

INTRODUCTION

The increasing demands made on all structural components and their harmonious cooperation in the airplane,

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*"Der 5 X 7 m Windkanal der DVL. Luftfahrtforschung, October 3, 1935, pp. 181-187.

have made the need for tests in large wind tunnels increasingly pressing, so that the DVL at last decided to build a large tunnel. The size of the tunnel was governed by the following points of view: Power plants with air-cooled engines do not lend themselves to model reproduction; the tunnel must therefore permit full-scale power-plant investigation. The supercritical investigation of airfoils necessitates Reynolds Numbers of several millions. To comply with both these demands would make a further increase in tunnel size of little advantage, considering the costs and time necessary for the experiments. For this reason, the choice fell to an elliptical jet section of 5 by 7 meters (16.4 by 23 feet) which, if necessary, may be enlarged to 6 by 8 meters (19.7 by 26.25 feet). In this stream, full-sized power plants or wings can be explored up to 4×10^6 Reynolds Numbers.

GENERAL ARRANGEMENT

The general arrangement corresponds to the 1.2-meter (3.94 ft.) tunnel of the DVL and the proved Göttingen prototype (figs. 1 to 3). The air is returned in a horizontal circuit to one side of the test building and flows within the 9-meter (29.53 ft.) test section as open jet from entrance cone to exit cone flare. The entrance-cone section is a horizontally placed ellipse with the axes 5 by 7 meters.

Occasionally it may be of advantage to increase both the length and section of the jet at lower top speed. With this in mind, the last 2 meters (6.56 ft.) of the entrance cone were designed as a supplementary cone, of iron, split horizontally and removable. With opened supplementary cone, the principal entrance cone becomes free and the jet section increases to 6 by 8 meters, and its length to 11 meters.

With its 2,700 horsepower power plant, a top speed of 65 meters per second (213 feet per second) is reached for the 5- by 7-meter cone. The air ducts of the tunnel are open, while the test section is housed within a building. An office building for the operating personnel and a workshop together with a preliminary assembly hall for preparing the tests, and connected by rails with the test building, complete the set-up.

AIR SUPPLY

Excepting the iron supplementary cone, the entire air channel is of reinforced concrete, according to the Zeiss-Dywidag method. The gage of the pipe including plastering, is 70 mm (2.8 in.). Two joints - in front of and behind the propeller - divide the pipe in three sections, supported separately and resting on sliding joints to take care of heat expansion. The two pipe bends are primarily supported in the elbows, which are reinforced by heavy concrete rings.

The entrance cone, being designed to accommodate the 5- by 7-meter as well as the 6- by 8-meter jet, is unusually large. The correct shape of both the entrance cone and the exit cone, was determined from model tests. The base of the exit cone carries a ring of openings which ensures a smooth (free from shock) exit of the air entrained by the jet. These openings - originally quite large because the exit cone itself is of reinforced concrete - were later reduced by 50 percent.

The propeller was mounted in the return passage for two reasons: first, because it reduces the pipe length as compared with the arrangement of propeller behind the exit cone; and second, because in this particular case, the elliptical jet had to be transformed in the circular section. The change-over from elliptical in the exit cone to circular section of the propeller, is gradual in the intermediate pipes.

The guide vanes are of reinforced concrete with correction blades of thin sheet iron at the trailing edges, intended for fine (or secondary) deflector correction (fig. 4). However, it was subsequently found that no correction was needed other than at the bend directly in front of the propeller which, as a result of interference effect of the motor shell aft of it, deflected less than 90 degrees.

As the tunnel, in view of the costs, was to be as short as possible without, however, endangering the flow through too abrupt diffusion, the guides themselves were utilized for diffusion. In two bends ahead of the propeller, the pipe section carried abrupt enlargements of approximately 8 percent. This relieves the diffuser between propeller and subsequent bend, so that it does not tend toward burbling of flow, even under detrimental conditions.

The change from circular to elliptical section aft of the propeller is effected just as gradually as the reverse process in front of the propeller. Directly before the cone, the air duct has an elliptical section of 10 by 14 meters (32.8 by 45.93 ft.), which is equivalent to a contraction ratio of 4 for the small, and of about 3, for the large cone.

In front of the cone is the honeycomb, consisting of 9,000 round tubes of 120 mm (4.72 in.) diameter, and 800 mm (31.5 in.) length. Contrary to usual tunnel practice, a honeycomb was originally provided, since the experience with the 1.2-meter tunnel had proved it not only to ameliorate the directional accuracy of the flow, but at the same time, effect a substantial reduction in flow turbulence.

Three vents are fitted between the last bends before the entrance cone. The opening of these vents provides for partial blow-off of compressed air, and at the same time ensures a supply of fresh air from all sides. The purpose of this arrangement was to provide a steady supply of fresh air when making gasoline-engine tests.

POWER PLANT AND SPEED CONTROL

The blower unit is an 8-blade adjustable propeller of $8\frac{1}{2}$-meter (27.88 ft.) diameter, mounted directly to the axle stub of a 2,700-horsepower multiphase-current short-circuited motor (fig. 5). The motor has change-over pole pieces, so that it can run at 125 or 250 r.p.m.. The low propeller-tip speed of 104 m/s (341 ft./sec.) was chosen for reasons of blower noise.

The motor rests on two strong supports and is cowled in. The two engine supports form at the same time two blades of the six-blade guide apparatus situated aft of the propeller, and intended for the removal of the slipstream rotation.

The blades are hollow and of cast silumin. All eight blades are adjustable in operation by one hydraulic servomotor, effected from a portable control desk, as is the entire motor operation.

The choice of power plant was governed by economical and normal operating reasons. Only multiphase current being available, the usual speed control by multiphase d.-c. transformer and d.-c. motor, would have entailed considerable expense. Aside from that, it was not thought advisable to install a d.-c. motor, which is more sensitive compared to the multiphase-current, short-circuited motor, in the center of the tunnel, where it is little accessible and serviceable.

For these reasons, it was decided to use the strongest kind of electric motor obtainable - that is, the multiphase-current short-circuited motor, coupled direct to the propeller, and to eliminate the transformers altogether. The control of the speed by adjustable propeller was, for the first time, attempted in this tunnel.

In order to insure automatic constancy of speed for the period of the test - once it had been chosen through the motor r.p.m. and the blade setting - the control, developed for the 1.2-meter (3.94 ft.) tunnel of the DVL, was employed. Slots provided in the antechamber over the entrance cone, at the point of maximum pressure, permit the compressed air to escape. The outgoing air quantity is regulated by vents and an Askania automatic jet-tube regulator, thus assuring constant speed in the test section. To be sure, this control impairs the performance factor of the tunnel, because the energy of the air escaping through the slots is wasted, but for large tunnels, it has the distinct advantage of minimum inertia and consequently, quicker action than any other control.

SIX-COMPONENT BALANCE

The balance was designed on the basis of special studies in the 1.2-meter tunnel. It is housed in a separate room above the jet (fig. 6). The room can be properly heated and is protected against wind and noise, so that both the personnel and the test instruments operate under favorable conditions. In point of fact, the noise interference is so small that normal conversation is possible up to about 40 m/s (131.2 ft./sec.).

An opening in the floor of the test chamber gives access to the structure carrying the wire-suspended model (figs. 7 and 8). Four wires form the edges of a pyramid, the top resting in an attachment fitting of the model. These fittings, recessed in the model, consist of spherical hinges which insure the model freedom from friction about any axis necessary for six-component measurements.

The fittings are provided with quick fasteners, so that a model can be exchanged within approximately 30 minutes. The suspension of the models is effected by means of two travelling stages, one of which may be seen in the background of figure 7. In case of necessity, that is, with light models - measurements of negative lift, high angles of yaw, etc. - the fittings can be linked through pre-tension wires with underground pre-tension weights, and given initial tension. To prevent these weights from oscillating and so disturbing the measurement, they are designed as damping plates, which are immersed in an underground water tank. Every part of the suspension exposed to the air stream is carefully streamlined. The drag of the whole suspension system without pre-tension wires, is only about one-third of the minimum drag of normal airfoil models, so that no shielding of the suspension was necessary.

The range of the balance permits lift and yaw changes up to $\pm 40^\circ$. Since streamline wires become unfavorable in yaw and tend to oscillate, the usual procedure of mounting the balance on a turntable, was foregone and the wire suspension including their supporting tubular frames and balances, were guided parallel to the flow in angle-of-yaw changes by means of a parallelogram control. This parallel guidance prevented the yawing of the streamline wires and insured a practically constant wire drag. Lift and yaw settings were effected electrically from an observation post.

The forces applied at the joints of the model were decomposed in lift, drag, and cross-wind force, and measured on balances as illustrated in figure 9. The whole is mounted on strong, dustproof, flat spring linkages. After a year's use, it has revealed no sign of wear or friction.

The utility of such a device is governed by the amount of rigidity of the entire assembly, so as to avoid deformations and errors in the force decomposition under maximum load. A check of the balance by simultaneous application of corresponding forces, revealed that a 1,000 kg (2,204.6 lb.) lift falsifies a 100 kg (220.5 lb.) drag by 0.3 percent, so that the rigidity of the balance is adequate, considering that a 1,000 kg lift for the best climbing range, is hardly attained even with abnormally large models.

The real instrument employed for the determination of the forces was based on the well-known beam-balance principle. Since, however, it was desirable to have the weighing and recording of the test values automatic, for reasons of intensive use of the tunnel, while the commercial beam balances were not accurate enough to suit our purposes, we developed an instrument to fit the particular requirements of the tunnel. This instrument is fundamentally an electrically controlled beam balance with substantially greater recording accuracy, fitted with a remote transmission which affords a record of the test data from a number of test stations on one test sheet in numerical print.

This instrument was employed for the automatic recording of the six air-force components and in conjunction with a bell jar for recording the jet velocity. A recording desk, on which the measured values of all test stations arrive, permits the working up of numerically printed test records from twelve test values, besides a set of curves of the six air-force components plotted against the angle of attack. The survey over the course of the measurement is effected on the basis of the curves, whereas for the evaluation, the much more exact numerical record is employed.

At the same time the balance was designed with a view of effecting model tests with running propellers. To minimize interference through current supply for the models and to simplify the installation of models with propellers, the suspension wires were all electrically insulated and given galvanic copper coatings so as to insure adequate conductivity. To combine great strength with good conductivity, the ball joints in the attachment fittings of the models were made of beryllium-bronze. The vertical wire leading to the rear end of the fuselage is hollow and holds 10 thin leads used for r.p.m. and temperature control for not more than four model engines. Once the model is slung from its suspension, its engines are automatically linked with the control desk in the test chamber. The model engines are compact d.-c. motors which, according to preliminary tests, are superior to the conventional multiphase-current motors when it is a question of defining the torque transmitted to the model propeller and through it, the installation efficiency of the propeller. For the particular arrangement of the large tunnel, this torque is determined from the armature current of the motors.

Another adjunct of the wind tunnel is the preliminary assembly hall facing the large entrance door to the tunnel, from which various special test equipment can be transported on rails into the tunnel. A torque stand for full-size free-wheeling propellers, has been completed. It consists of a movable support carrying a long shaft in a pipe and using a 650-horsepower gasoline engine as drive. The propellers are mounted at the head of the long shaft so that the flow in the plane of the propeller suffers no interference by the drive and the test installation. The thrust and torque of the propeller are hydraulically measured in metering boxes on the propeller hub and read from the sheltered observation post situated below the jet. This post also serves for the entire control of the drive as well as the measurement of all other essential propeller factors.

The same base may equally well be employed for testing engines with running propellers. Since the equipment necessary is, however, intended only for the mechanical testing of power plants - that is, permits no air force measurements, a third arrangement is being developed at present, designed to permit the testing of complete power plants, along with the determination of the external forces. This arrangement is to consist of a strong, portable, three-component balance, capable of supporting a whole airplane, including running engine and propeller.

OPERATION AND JET CHARACTERISTICS

The operation of the tunnel has been decidedly affected by this new drive. Fundamentally, all investigations had to be made for several speeds, owing to the adjustable propeller, and other than the customary auxiliary aids had to be employed for flow correction.

The very first test runs revealed that the normal guide apparatus situated behind the propeller was not capable of reducing the slipstream rotation enough at all blade settings. At extreme settings the rotation was still so pronounced that the flow at the deflector vanes situated aft of the diffuser, became separated and so disturbed the entire velocity distribution of the jet. For this reason, the guide apparatus was lengthened to approximately three times its depth, which lowered the slipstream rotation sufficiently for any blade setting.

Another fact noted, was that the velocity distribution was satisfactory for the median blade setting of the propeller, but manifested considerable disturbance above or below it, as a result of uneven thrust grading of the adjustable propeller. This defect resulted in an approximately 5-percent greater velocity on the jet boundary (for maximum blade setting) than in the jet center, and vice versa for minimum blade setting.

To minimize this defect, we mounted a screen of 2.5 mm (0.098 in.) wire gage and 13 mm (0.512 in.) mesh width, before the honeycomb and thus closed off the entire pipe section. This screen reduced the error in velocity distribution to less than one-third, so that now the velocity in the jet differs only 1.5 percent for unfavorable blade setting (fig. 10). At the optimum blade setting (30 and 60 m/s (98.4 and 196.8 ft./sec.)), the maximum velocity discrepancy on the long axis of the jet section amounts to about one-half percent; that is, the figure obtained in good tunnels.

The energy loss in the screen requires approximately 8 percent more horsepower. Even so, despite this waste, the quality of the tunnel equals that of normal wind tunnels with fixed-pitch propellers, because the adjustable propeller effected the saving of the multiphase-current d.-c. transformer, with its far greater losses, especially at low jet velocity, than the screen.

The jet turbulence was explored before and after mounting the screen, and found to be the same. The investigation was made with a 150^{mm} (5.91 in.) polished steel sphere, with which previously, the critical Reynolds Number of the atmosphere at $R_k(c_W = 0.3) = 3.85$ to 4.05×10^5 (depending on gustiness) had been established in free flight. The measurement was made at several points of the long axis of the jet section. The critical Reynolds Number of the tunnel on this line averages $R_k(c_W = 0.3) = 3.67 \times 10^5$ (fig. 11); that is, it reaches, as regards turbulence, the figures of the best tunnels hitherto built and approaches flight condition very closely.

The accuracy of the jet as regards direction, was also explored and improved as much as possible. To insure favorable values in this respect also, the guide apparatus aft of the propeller was fitted with secondary correction blades and a correct setting of these blades experimentally established. The maximum deviation of jet direction from the mean direction is at present $\pm 0.5^\circ$ on the horizontal jet axis - a figure which probably will be improved upon further (fig. 12). Comparison of these figures with the performances of other large tunnels is impossible, because not enough information has been published on the subject.

The conventional practice today is to test the jet characteristics without suspending a model in the air stream. Since it is possible that a large model, compared to the jet, may perceptibly change the jet characteristics, we tested the turbulence and velocity distribution at sufficient distance before a model wing of 5 m (16.4 ft.) span. It was found that the turbulence before the model does not increase even when the wing is considerably stalled. The turbulence produced by the wing is therefore completely removed. The wing causes, at maximum lift, an additional disturbance of about 2 percent in the velocity distribution. These tests have removed all doubt which may be voiced against the use of the elliptical jet with correspondingly large models.

At the beginning of operations, the whole air column manifested longitudinal oscillations which, after reducing the slot in the exit cone, were reduced to approximately one-third their amplitude. These oscillations are now very rarely observed, and then only at low propeller speed, where they can be readily avoided by increasing the speed.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

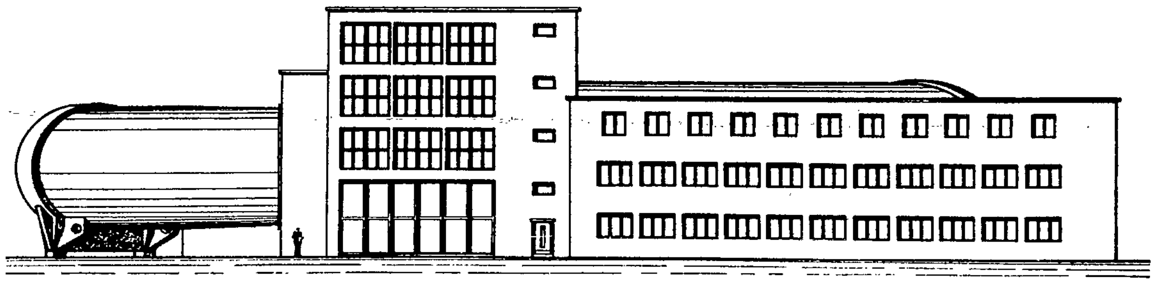

Figure 1.- Front elevation of the 5 by 7 m (16.4 x 23 ft.) wind tunnel.

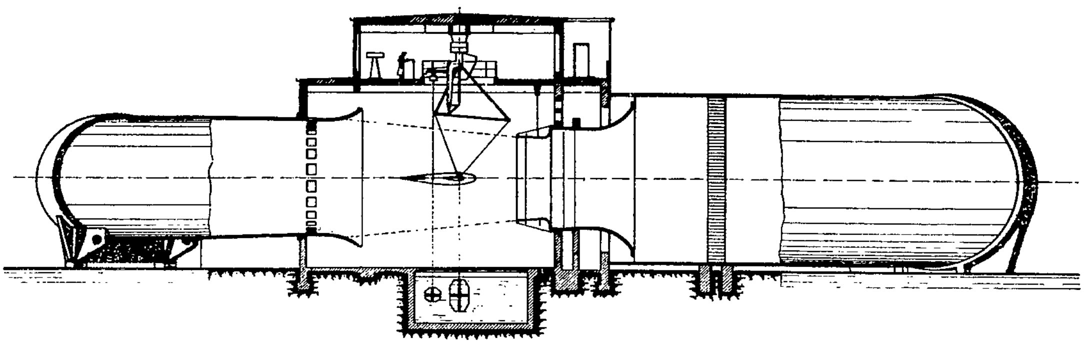

Figure 2.- View of test room.

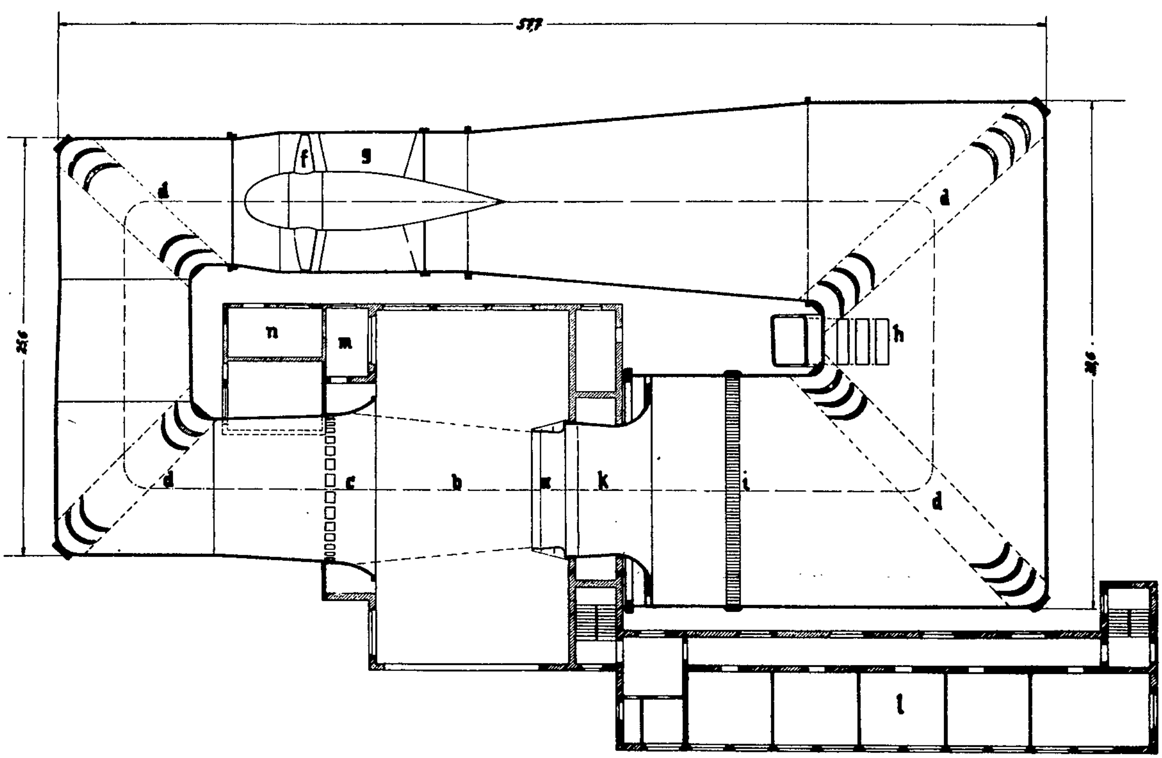

Figure 3.- Cross section of tunnel at level of tunnel axis.

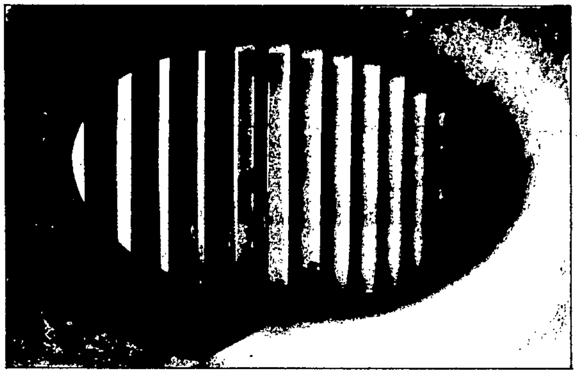

Figure 4.- Guides with vent aft of diffuser.

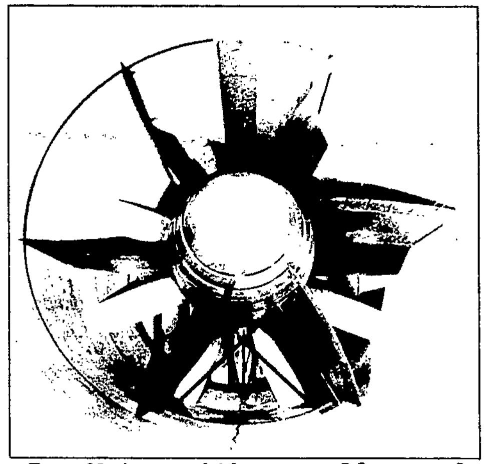

Figure 5.- Motor with propeller and guides (upstream).

Figure 6.- Test room with six-component balance.

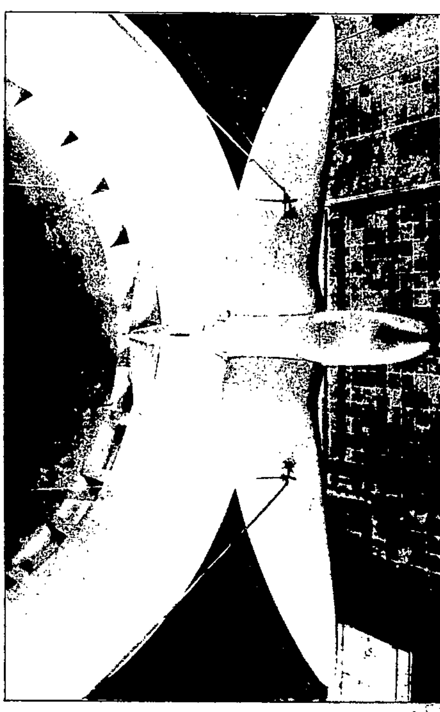

Figure 8.- Method of model suspension.

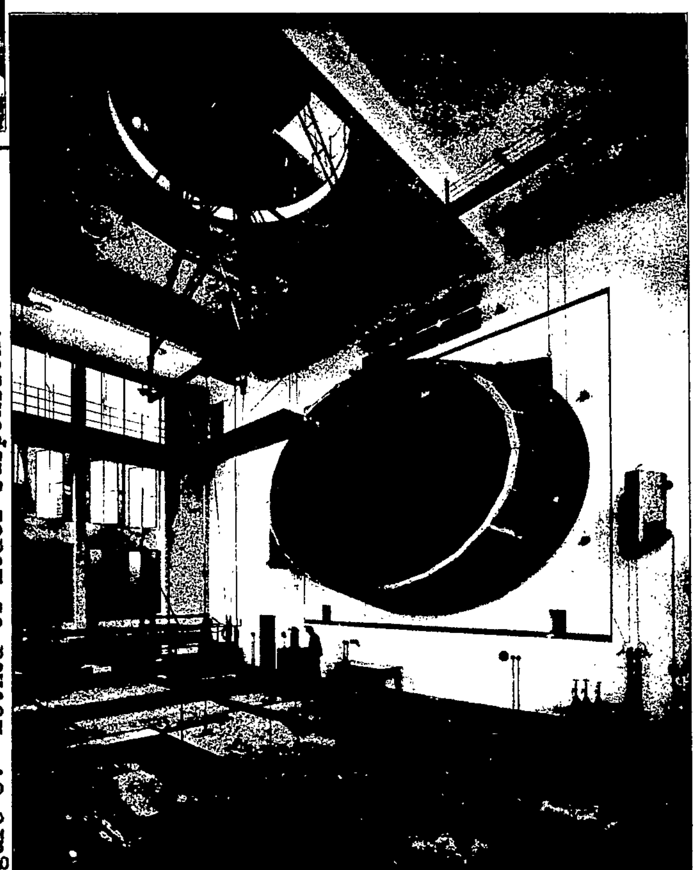

Figure 7.- View of entrance cone, and suspended model airfoil.

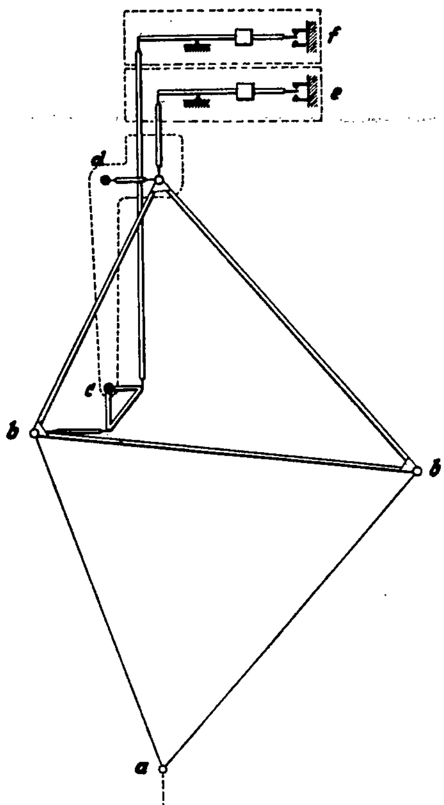

Figure 9.- Force decomposers.
a, Ball joint
b, Wire fitting
c, Lever
d, Parallel guide
e, Lift balance
f, Drag balance

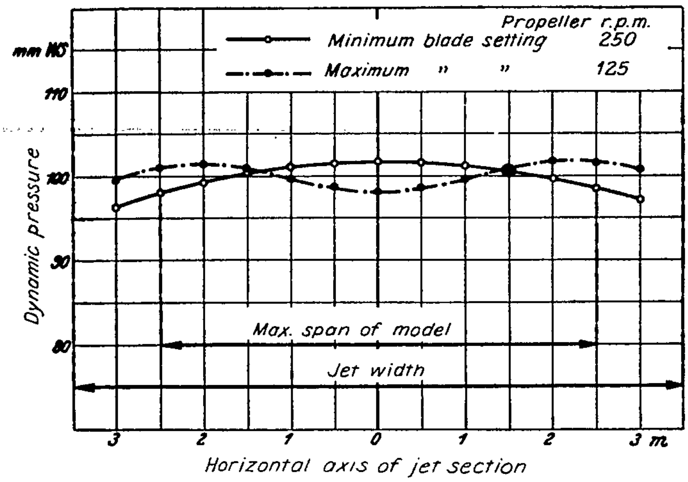

Figure 10.- Dynamic pressure curve on the horizontal axis of the jet section for extreme propeller-blade setting.

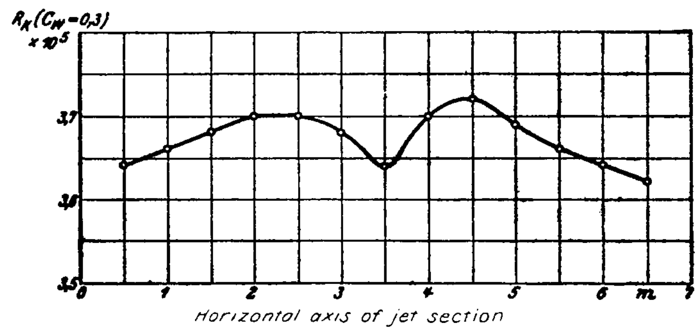

Figure 11.- Jet turbulence investigation; $R_k(c_W = 0.3)$ on the long axis of the jet section.

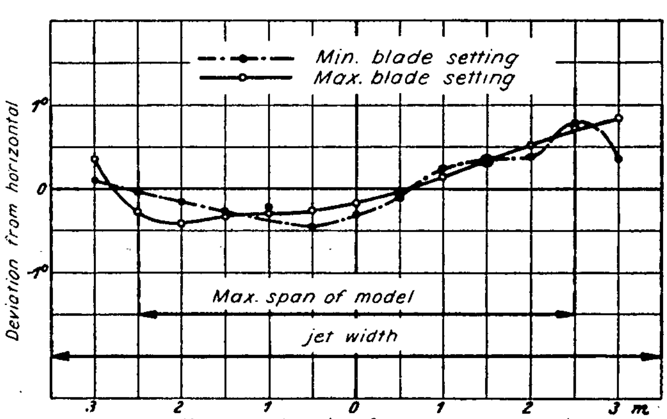

Figure 12.- Direction curve on horizontal axis of jet section for extreme propeller-blade setting.